LATERALIZED WARNING STIMULI, PHASIC ELECTROCORTICAL AROUSAL, AND REACTION TIME

By

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DEDICATED TO THE MEMORY OF MRS. SYLVIA DIACHENKO

YOUR VOICE IS NOW STILL,
BUT YOUR ECHOES ARE STILL LOUD ENOUGH
TO HAVE LASTING EFFECTS ON US

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The traditional approach to the study of behavior and its relationship to brain structure has been molded by the emphasis of classical psychology on the organization and direction of behavioral events. Thus, neuropsychological investigation has been most fruitful in the study of the neural substrates of cognition, language, and perception.

Recently attention has been turned to the intensive aspects of behavior or, more correctly, the arousal or activational components of behavior. The activation process is often viewed as the energizing component of a particular perceptual experience of behavior. Psychological constructs attributed to activation have included emotion, motivation, and attention. All of these processes have been notorious for their difficulties in measurement and interpretation.

Most recently, however, the trend has been to merge the directional and activational aspects of behavior into a unified concept. This has largely resulted from the study of the neurophysiological integration at all levels of the neuraxis attributed to the ascending and descending reticular activating system.

Clinical observation has led to speculation that the activational aspects of neural processing are functionally predominant in the right cerebral hemisphere. The present investigation was concerned with investigating this hypothesis via both behavioral and electrophysiological means.

Twenty-four experimental subjects participated in a simple reaction time experiment in which two thirds of all trials were preceded by a warning stimulus in either the left or right visual half-fields. Electroencephalographic recordings from both cerebral hemispheres were made coincident with the reaction time trials. As expected, reaction times with the preferred right hand were significantly faster when preceded by a warning stimulus presented to the right hemisphere.

The electroencephalographic data, however, were not consistent with the original hypothesis in that the right parietal leads responded equally to all warning stimuli while the left parietal leads were differentially suppressed in terms of alpha power. This pattern of results is discussed from the viewpoint of alternative explanations with the most likely interpretation that suppression of alpha power represents both information processing and arousal components with the information processing component predominant. Given this interpretation the electroencephalographic results are consistent with previous work involving material specific warning stimuli in the simple reaction time paradigm.

While not conclusive, the present data are supportive of the contention that the right hemisphere is functionally predominant in the phasic arousal response.

CHAPTER I

INTRODUCTION

Since the early phrenologists attempts have been made to relate complex mental attributes to specific structures in the central nervous system. With the publication of Carl Wernicke's (1874) work on language disturbances, however, true neuropsychological investigation began. That is, not only did Wernicke provide evidence for the localization of specific forms of language disturbance, but he set forth a theory which tied the phenomena of aphasia to existing neurological knowledge.

It is in this tradition that neuropsychology has progressed to the current rapidly expanding field of investigation. As such, the main attention of neuropsychology has been drawn to the neural substrates of perception, cognition, and response to the external environment and internal mileau. Thus, such early investigators as Kohler (1929) centered interest in how the sensory-perceptual organization of the brain is imposed on the extraorganismic physical stimulus. Karl Lashley's productive, if controversial, contributions to neuropsychology also reflect the assumption that behavior involves primarily the organization and neural processing of external events. Even in his (1963) statement of his concept of "mass action" it can be noted that the original dynamism or source of excitation remains extraorganismic and his "dynamic relations among the parts of the nervous system" at root can be interpreted as a constant change in organization as a result of external stimulation. It should be noted, however, that Lashley was among the first theoreticians to express the possible role of intraorganismic activating factors when he attributed memory systems to a "tonic activity" which determines the direction of attention (Lashley, 1958).

Even the classical cognitive psychologist Bruner's contributions remain oriented on the nervous system as an intermediate variable whose function is the organization and interpretation of sensory events. Perceptions and overt responses emerge only on the basis of these "summary integrations" (Bruner, 1957).

From this discussion it can be seen that from the viewpoint of historical neuropsychology, behavior is the end result of the organizational and information processing aspects of brain function consequent to external stimuli.

The present investigation, however, is concerned with the activational or intensive components of behavior and the possible lateralization of the neural functions responsible for the expression of this aspect of behavior. Thus, the following discussion will center around the concepts of behavioral arousal or activation in psychology and neurophysiology. As will be seen, the two areas of study are often closely related when activation is discussed.

CHAPTER II

ACTIVATION AS A PSYCHOLOGICAL CONCEPT

The concept of arousal or "activation" has long been of central importance in psychological theories concerned with the intensive components of behavior (Duffy, 1934, 1957, 1962). Since the earliest use of this concept it has always been deeply involved with the physiology of the organism as well as with the more overt aspects of behavior. Cannon (1915), for example, defined activation as a diffuse excitation of the sympathetic nervous system. More recent investigators have elaborated the concept of arousal into several discrete components and have implicated such diverse psychological concepts as emotion and attention directly with arousal mechanisms (Lindsley, 1970; Schacter, 1970).

As has been indicated, the concept of arousal or activation has been of importance in theories concerned with the intensive aspects of behavior. While it has often been difficult to identify the psychological concept of arousal without recourse to physiology, the present discussion will attempt to cover the major psychological conceptualizations of the term with a later section to be concerned with the physiological and psychophysiological aspects of arousal.

Probably the foremost proponent of the concept of activation as a psychological concept was Elizabeth Duffy. In a long series of publications she attempted to dispose of such introspection tainted concepts as emotion with her concept of activation (Duffy, 1934, 1941, 1962). For Duffy activation refers not to the overt activity of the organism but to the release of energy into various internal physiological systems in preparation for overt activity. The overt activity need never occur, but if it does, activation is its constant accompaniment and sustainer. For Duffy activation is both general and specific. Since stimulus situations vary, the patterning of activation must necessarily vary to adjust to the particular conditions of the moment. She also stated that arousal accompanied by inhibition would necessarily show different physiological patterning from arousal expressed overtly in motor behavior.

Thus for Duffy activation was conceived of as a physiological intervening variable, produced by certain stimulus factors and resulting in certain effects upon response. For Duffy the major problems with the concept of activation lay in the area of methodology; that is, what should be measured and at what intervals. How many different responses from different physiological systems should be combined to indicate an overall measure of activation. Despite these problems, Duffy insisted that activation seems to be related to almost any response an organism makes and it can be modified by almost any induction, such as observable stimulation, or by the organism itself with such activities as attending or thinking.

Lindsley (1950, 1957, 1970) while basing most, if not all, of his speculations on electrophysiological data can also be grouped among psychological theorists of arousal. He attributed such psychological processes as attention, emotion, and motivation to a physiologically based diffuse arousal system involving the reticular activating system (RAS), the thalamus, and the cerebral cortex. He viewed activation as a unitary phenomena which was expressed on a continuum in behavior which extended from the low arousal of deep sleep to the high arousal of emotional excitement.

Lindsley's work was almost entirely based on observation of EEG changes during differing behavioral states. This limitation of his work to one physiological system probably is the basis for the later disfavor of his concept for a more diverse two component theory of activation (Routtenburg, 1968). This "two arousal" theory posits two forms of activation involving two separate, but overlapping, systems of arousal. The first is a tonic system involved with sleep and wakefulness of the organism. The second or phasic system controls activation by responding to significant environmental stimuli. It is this second or phasic system with which the present investigation is concerned.

While the present discussion is far from complete it has presented the two major theorists in this area and has demonstrated the diverse psychological processes which have been attributed to the concepts of activation or arousal. Henceforth these two terms will be uniformly used to indicate phasic and tonic processes respectively.

Physiological Bases of Activation

Although activation was initiated as a psychological concept its subsequent development has been closely tied to modern neurophysiological work on the brainstem RAS (Morruzi and Magoun, 1949; Samuel, 1959). The fundamental work of Morruzi and Magoun demonstrated the existence of widely spread neural pathways which ascend through the central reticular core of the brainstem and which are apparently capable of exerting a diffuse activating influence upon the cerebral cortex; but it remained for other investigators with refined electrophysiological tools to demonstrate the importance of the RAS for such important psychological processes as learning and attention.

As part of their earlier work Morruzi and Magoun demonstrated with their experimental animals that the blocking of the EEG alpha rhythms could be induced by electrical stimulation of the brainstem RAS or by stimulation of the various sense modalities. Interruption of the ascending RAS by lesion abolishes this activation of the EEG and produces patterns similar to those of sleep with behavioral patterns characterized by hypokinesis, and somnolence (Lindsley, Schreiner, Knowles, and Magoun, 1950). It remained for French, Hernandez-Peon, and Livingston (1955) to demonstrate via EEG measures of RAS activity that the RAS could be activated by connections with the cerebral cortex.

While the ascending system elaborated by the early work of Morruzi and Magoun (1949) was sufficient for understanding sleep and wakefulness phenomena, such processes as voluntary attention or "wakefulness of choice" required more complex neural processes. Since the higher mental activities involved with voluntary attention seem to have elaborated with the development of the neocortex, it was logical to hypothesize that the neocortex has functional connections with the RAS. This inference led French and his coworkers to search for corticoreticular connections. As they expected, evoked potentials were recorded from the RAS when single stimuli were applied to certain areas of the cerebral cortex. These areas included the sensorimotor cortex, the frontal eye fields (Broadman's Area 8), the parietal-occipital transitional cortex, the tip of the temporal lobe, the cingulate gyrus, and the superior aspect of the mesial frontal lobe. Their physiological techniques were later confirmed by formal neuronography.

The participation of these areas in wakefulness and arousal was also demonstrated by Segundo, Naguet, and Buser (1955). They showed that when wakeful animals were stimulated in these cortical areas, and they demonstrated a typical orienting response despite the lack of significant environmental cues.

Thus, it would seem, that for higher animals these descending connections with the RAS play a role in selective arousal to complex stimuli, particularly those with acquired significance through learning.

Probably the foremost physiological investigator and theorist of phasic activational responses and their implication for psychological processes has been Raul Hernandez-Peon (1966). While his discussions have centered around attentional mechanisms, he specifically stated the hypothesis formulated above that phasic responses in general are the evolutionary product of the combination of brain mechanisms underlying wakefulness and the more recently evolved systems for corticofugal excitation of the RAS. He reasoned that the most suitable anatomical localization of the neural system involved in the phasic integration of experience should be in a region of convergent and divergent pathways connected to all of the neural circuits participating in behavior. For Hernandez-Peon, the only structure to meet these requirements is the diffusely branching reticular neurons of the rostral brainstem. Not only does this system recieve inputs from all sensory systems, the neocortex, and the limbic system, which all must be involved in sensory discrimination, memory, emotion and motivation, but long ascending and descending neurons from this system have been shown to establish connections at all levels of the nervous ysstem (Scheibel and Scheibel, 1958).

Thus, Hernandez-Peon states the RAS is a diffusely arousing system which has developed phylogenetically to maintain the wakefulness of the organism; but, with increasing elaboration of the cerebral hemispheres has begun to participate in such higher order processes as attention, emotion, and motivation via afferent and efferent connections with these structures.

It is beyond the scope of this discussion to elaborate on the anatomical and physiological investigations supporting this position, but suitable reviews of this area of investigation are available (Hernandez-Peon, 1969; Henry Ford Symposium on the Reticular Formation of the Brain, 1958). The remainder of this discussion will concern the evidence for the lateralization of the phasic arousal mechanism in the cerebral hemispheres.

Lateralization of Phasic Activation

Until recently the concept of the global unity of mind has been uncontested despite the evidence for lateralization of language functions and the further localization of aspects of language within the left cerebral hemisphere. The recent work of Gazzaniga (1970) on individuals with complete bisection of the corpus callosum has demonstrated the existence of two separate brains each with specialized functions and modes of information processing which complement each other. This work and the observations of clinical neuropsychology that the differential effects of brain lesions depend on their localization and lateralization have served to dispel the myth of global unity of function. Only recently, however, have workers in this area directed their attention to the defects in phasic arousal demonstrated by their patients.

Clinical observation of patients with right hemispheric brain lesions has indicated that such individuals, especially when lesions involve the right inferior parietal lobule, demonstrate a complex syndrome involving multimodal inattention to the contralateral left half of space, denial of their physical defects, and changes in their emotional and motivational states. Numerous theories have been proposed to account for these defects and have ranged from statements that they are due to defects of sensory processing (Battersby, Bender, and Pollack, 1956), defects in somatosensory localization, (Denny-Brown, Meyer, and Horenstein, 1952), or a defect in attention (Critchley, 1949). In any case, it has become common to refer to this syndrome as the unilateral neglect syndrome.

Such symptoms as mentioned above almost uniformly occur after lesion of the right hemisphere, but have been observed after left hemispheric lesions. When they occur after left hemisphere lesion, however, they are often transient and elicited only by the most sensitive of tests.

Recently Heilman and Valenstein (1972) and Watson, Heilman, Cauthen, and King (1973) have presented the hypothesis that the unilateral neglect syndrome is the result of a defect in phasic arousal due to disconnection of some part of a cortical-RAS-cortical phasic arousal loop. It is interesting to note that the areas of cerebral cortex identified by these investigators as being involved in such a phasic arousal loop are the same areas identified by French et al. (1955) as showing corticofugal connections with the RAS.

The problem of the prepotence of the nondominant for language right hemisphere in this pahsic arousal process remains. Evidence does exist, however, for localizing this function.

Utilizing reaction times as a measure of activation Heilman et al. (1978), has shown that patients with unilateral neglect were very slow in responding to reaction time stimuli despite the fact that stimuli were presented to both visual fields and the uninvolved ipsilateral hand was utilized in responding. Warning stimuli which has been shown to increase EEG activation and markedly improve reaction time performance (Lansing, Schwartz, and Lindsley, 1959) were also shown to have no effect on patients with neglect even when they were presented to the uninvolved hemifield.

The fact that the activation defect resulting from right hemisphere lesions is bilateral is suggested by investigations of Gainotti and Tiacci (1971) and Albert (1973). They have shown that patients with neglect make errors in the field contralateral to their lesions as expected, but also make more errors than controls in the half field ipsilateral to their lesion.

Even more significant for the present discussion is data gathered from normal nonlesioned subjects. Beck, Dustman, and Sakai (1969) noted that cortical evoked potentials (CERs) were always greater in amplitude over the right parietal cortex with increasing behavioral arousal of their subjects. Bowers and Heilman (1976) gave 16 normal subjects either a verbal or nonverbal warning stimulus followed by a neutral reaction time stimulus. Reaction times from the right hand were significantly faster with verbal warning stimuli than with nonverbal warning stimuli. There were, however, no significant differences between type of warning stimuli for the left hand. Wood and Goff (1971) reported that auditory CERs were different over the left cortex though identical over the right cortex during linguistic and nonlinguistic analysis of the same signal.

It would seem from the previous discussion that the left hemisphere is alerted more by linguistic stimuli such as verbal material while the right hemisphere is alerted by all stimuli. Such a conclusion would support the position that the right hemisphere is dominant for the processing of the environment in terms of significance and, thus, functionally more significant for the phasic activation response.

Measurement of Activation

Among the most crucial questions to have risen regarding the activational components of behavior is how these variables are to be measured. The answers to these questions have been many and varied. Duffy (1962) suggests that the most appropriate measure would be of the total metabolic activity of the organism, such as that obtained with the determination of total oxygen consumption. Freeman (1948) has pointed out the difficulty of this measure for psychologists who are traditionally interested in the changes in activation as a result of changes in the stimulus situation. He indicates that most organ systems have an energy store which is sufficient for responding to normal stimulus displacements without affecting the total energy consumption of the organism.

Despite the difficulties in measuring activation demonstrated by the example of total oxygen consumption, Duffy states that any survey of the literature would indicate that a wide variety of measures of physiological response show consistent changes with changes in the energy requirements of the situation. The direction of these changes, she states, are consistent as the individual goes from states of low activation to states of extreme activation as in excitement. Moreover, changes in any one measure are most often correlated with changes in other measures; although these correlations may vary from individual to individual. Thus any one measure might be taken as a rough indication of the general level of activation.

As has been indicated, the more recent dissection of the activation processes into tonic and phasic components has further complicated the problem of measurement of activation. Considerable care must be taken in determining whether or not the changes in activation under study are related to the component of interest.

With these problems in mind, the following discussion will concern itself with the major measures of activation with special reference to those measures to be utilized in the present investigation.

Skeletal Muscle Tension

Classical studies of the tension of the skeletal muscles via their electrical activity by Jacobsen (1938) and Max (1935) have shown that increased tension in muscle is a regular accompaniment of such psychological processes as "attention." Variations in muscle tension as represented by the electrical activity of the muscle during a repetitive task have been utilized as a measure of "alertness" (Travis and Kennedy, 1947; Kennedy and Travis, 1948). They found that muscle action potentials measured by the electromyograph (EMG) decreased progressively as their experimental subjects became less alert. Their index of alertness was simple reaction time and efficiency in performing their task. Thus, as reaction time increased and more errors were made, decreasing muscle action potentials could be noted. With appropriate stimulation of their subjects shorter reaction times could be elicited and accuracy increased. With these increases, a progressive increase in muscle potential amplitude was noted.

Despite the seeming validity of muscle tension as a measure of activation it has been only rarely used in the more recent studies of these processes. The reasons for this lack lie in the difficulties in gaining reliable measures. When electrical measures of muscle potentials are correlated with other indices of muscle activity such as grip strength or eyeblink rate (Malmo and Smith, 1955), the correlation coefficients have been insignificant. Other investigators such as Nidever (1959) have sought the existence of a general factor of muscle tension by recording muscle potentials from a large number of muscle groups from a large number of subjects. He was able to demonstrate such a factor, but found that factor analysis of these variables measured while the subject was in an aroused state produced the same factor structure as in the resting state. Davis (1956) has debated the existence of a general factor of muscle tension and has proposed that there may be many patterns of muscle activation and that any one factor structure may depend on the muscle groups selected for study.

Goldstein (1972) also lists several confounds in the measurement of muscle tension including age, temperature, and electrical artifacts which are often difficult to control experimentally. Voas (1952) reported high test-retest reliabilities for EMG, but this was found to vary among muscle groups complicating the picture even more.

To summarize, the skeletal muscle potential would seem to offer one avenue by which the arousal or activational components of behavior might be measured. However, this variable has not come into common use in psychological investigation for several reasons, among which are the difficulty in gaining artifact free measures and the difficulty in choosing relevant muscle groups.

Electrical Resistance of the Skin

The transient responses of the skin in terms of its electrical resistance or conductance are also among the oldest physiological measures used in psychology. These responses, commonly known as the Galvanic Skin Response (GSR), or the psychogalvanic reflex (PGR), have also recently been utilized appropriately, and inappropriately, as measures of activation. Part of the difficulty with GSR measures is the number of measurable aspects of electrodermal activity available. When GSR is used it is not often clear what is being meausred. It can be the actual skin resistance or conductance, the response frequency, the amplitude of responses, or the amplitude of a single response to a specified stimulus presentation. These measures are not interchangeable, since they may have widely differing relationships to the variable under study.

To demonstrate this problem, Johnson (1962) indicated that at higher levels of induced subject activation the frequency of spontaneous GSR responses (responses not linked temperaly to a stimulus) remains relatively constant as activation increases, but the amplitude of time locked responses falls off.

Prior to the dissection of the arousal process into tonic and phasic components most of the major GSR studies were similar to that of Levy, Thaler, and Ruff (1958) who demonstrated that sleep was accompanied by high skin resistance. It was not clearly reported, but it would appear that these workers were measuring the slow changes in resistance rather than short spontaneous fluctuations in skin resistance. Alertness was accompanied by stable low resistance, and various levels of sleep could be identified by various GSR patterns.

Phasic GSR responses to loud stimuli were demonstrated by Landis and Hunt (1939). They showed that sudden, unexpected noises produced a uniform and sudden drop in skin resistance with variation in the response correlated with the intensity of the stimulus and the "surprise" value of the stimulus.

Duffy (1962) summarizes her discussion of skin resistance and conductance responses by stating that the one uniformity across studies of these responses is their variation with the demands of the experimental task and the level of arousal of the subject attributable to the significance of the stimulus situations.

Even more recently, Heilman, Schwartz, and Watson (1978) utilized the amplitude of the GSR response to electrical stimulation in studying patients with the unilateral neglect syndrome. They hypothesized that patients with neglect would show a defect in their GSR responses even if these responses were recorded from the uninvolved extremity ipsilateral to their stroke. The data confirmed their hypothesis to such an extent that parametric statistical procedures were inappropriate. Patients with the neglect phenomena produced no responses in over 96 percent of the trials, while patients with homologous left hemisphere lesions produced reliable GSR responses which, when compared to responses of normal subjects, proved to be significantly larger. These findings supported Heilman et al.'s hypothesis that the neglect syndrome is mainly a defect in phasic activation.

Thus, it would appear that the electrical responses of the skin provide a useful index of activation or arousal. The difficulties with this measure are attributable to the wide variety of measures derived from skin resistance available to the experimenter and the responsiveness of the GSR to both tonic and phasic components of the arousal process. Considerable care must be taken in the choice of measure and the conditions under which experimentation is pursued. Individual variations in the tonic arousal of subjects might obscure the effects sought in phasic responses of the GSR and produce erroneous conclusions. It would seem, though, that carefully designed and controlled studies of the arousal and phasic activational processes are possible utilizing the skin resistance measures.

Electrical Activity of the Brain

Brazier (1961) has provided an excellent historical perspective on the discovery and rediscovery of the electrical potentials of the brain. These potentials were first demonstrated by Richard Caton (1975), but the accepted discoverer of the usefulness of these potentials was Hans Berger, a psychiatrist. Utilizing a system of vacuum tubes for electronic amplification of the brain potentials called the electroencephalograph (EEG), Berger (1929) was able to elucidate two of the most common electrical rhythms of the brain. He was able to demonstrate the typical changes of the EEG in epilepsy.

This ability to record electric signals from the brain of a conscious, reporting human being gave rise to great hopes for understanding the mind-brain relationship. Despite the apparent disappointing results of studies along these lines, they continue to the present day.

With the discovery of Morruzi and Magoun (1949) that stimulation of the primitive mesencephalic reticular formation produced EEG changes and behavioral alerting similar to that of peripheral stimulation, the concept of arousal was given new meaning and the central place of the EEG in modern neurophysiology and psychophysiology was assured.

Interestingly, the original waves of brain electrical potentials demonstrated by Berger (1929) as the "alpha" rhythm (8 - 13 Hz.) are more probably "inaction" potentials as they are best recorded while the brain is at rest (Walter, 1944). The electrical potentials recorded in the EEG have been shown to be the resultant of large aggregates of cortical cells whose activity is determined by the influence of subcortical centers (Jasper, 1954).

The EEG pattern characteristic of the alerted, stimulated subject is fast, low frequency waves called "beta" waves (13 - 30 Hz.). This has been variously interpreted as inhibition by a specific active area of the cortex of the wider, spontaneously active regions of the brain, interference by sensory influx with resting rhythms tending to produce desynchronization of the multicellularly determined rhythmic pattern, or disruption at the subcortical levels of the presumed pacemakers of the cortical alpha rhythm.

Interestingly, however, the desynchronization of the alpha rhythm seems to depend more on the attention of the subject or the "surprise value" of the sensory stimulation rather than the stimulation per se. Lindsley (1950) was able to demonstrate that the EEG was reliably changed or blocked from the resting alpha rhythm to the fast, low voltage beta rhythm by both light or sound stimuli, but, after repeated stimulation, this blocking ceased to occur. He stated that the initial effectiveness of a stimulus in blocking the EEG was its "arousal aspect."

Further work has proven that the EEG phenomena of synchronized alpha and desynchronized beta rhythms depend on a complex physiological system involving the reticular activating system, its upward projections through the thalamus and hypothalamus, and cortical projections from the thalamus (Lindsley, Bowden, and Magoun, 1949).

The dynamics of the EEG arousal or desynchronization reaction are interesting in that they seem to result from inhibition of the cortex. Whittlock et al. (1953) observed in both chronic and acute animal preparations that the desynchronization reaction is associated with arrest of activity in many cortical units. This seeming contradition of cortical activation expressed as neurophysiological inhibition has been explained by Hernandez-Peon (1965) who proposes a "multi-inhibitory oligofacilitory" model of EEG arousal. This model postulated that during wakefulness, reticular influences on the cortex are constantly shifting in space and degree and between inhibitory and facilitory components with inhibitory far exceeding facilitory components. Thus, facilitation is restricted to those neural circuits necessary at any given moment for a particular physiologic situation while inhibition prevents interference of extraneous impulses on the selected pathways.

While the EEG has proven to be one of the most useful tools in the measurement of the brain components of activation, it again is responsive to both the tonic and phasic arousal components. Lindsley (1944) described the typical changes in the EEG which occur with differing levels of sleep and recent research has been able to determine the presence or absence of dreams on the basis of the typical EEG pattern produced by this state. In the case of the present investigation the EEG measure is one of the stimulus bound changes involved in the phasic activation system.

Behavioral Measures of Activation

The behavioral measurement of activation phenomena has taken many forms. These have included such diverse measures as the amplitude of the knee jerk reflex discussed by Duffy (1962) to assessing the force of motor movements reported in the same review. For the most part, however, these measures have been of the general quality of performance on experimental tasks and of reaction time (RT). The present discussion will limit itself to these latter measures.

The traditionally accepted relationship between activation and the quality of performance has been the inverted U-shaped curve wherein at both low and high levels of activation, the quality of performance falls off. An early study of this relationship is that of Stauffacher (1937) who measured the ability of experimental subjects to memorize nonsense syllables under varying degrees of induced muscle tension. He found that moderate degrees of muscle tension facilitated the learning of the syllables, and that learning fell off with both increases and decreases from this middle level of muscle tension. The effect of induced tension varied between subjects, however, with poor learners benefiting the most from induced tension. Stauffacher suggested that good learners were already operating at their optimum level of tension while poor performers on this task were not. Shaw (1956) also demonstrated increased memory for tachistoscopically presented digits under moderate levels of induced muscular tension measured by grip dynamometer. The optimum tension varied as a function of task difficulty, with a level of tension one quarter of the subject's assessed maximum sufficient to improve memory at all levels of task complexity. Increasing the length of the digit string required increasing levels of tension to demonstrate facilitation.

Additional support for the inverted U curve was provided by Stennet (1957) who recorded palmar skin conductance and EMG potentials during an auditory tracking task. With suitable controls for learning, and when interactions with the order of presentation of the tracking stimulus were partialled out of his data, the auditory performance scores were found to be related to both physiological measures in the expected manner. That is, when the physiological measures indicated both high or low levels of activation, performance scores were decreased from those obtained from the middle of the activation domain.

The relationship between RT and activation also has considerable history. Kleitman (1939) demonstrated that RT varied with the time of day with a progressive decrease during the morning and afternoon and increasing RTs in the evening and night hours. Kleitman demonstrated this diurnal variation for both simple and choice reaction times and attributed the changing RTs entirely to changes in body temperature. Teichner (1954) and Woodworth and Schlosbert (1954) also review a lengthy series of studies relating stimuli with known effects on activation with changes in RT. Among these factors were drugs, anoxia, exercise, and changes in motivation. These studies are not without ambiguity, however, and it is often difficult to tease out which component of the arousal process is under study.

It would seem appropriate, though, to ascribe the simple RT paradigm as a measure of the phasic activation process insofar as the tonic effects of time of day and other tonic arousal components of the RT are controlled. EEG changes associated with significant environmental stimuli are also best ascribed to the phasic activation process.

The relationship between RT as a measure of behavioral phasic activation and EEG variables as an index of physiological phasic activation has been extensively studied over the past twenty years. Several RT experiments have demonstrated a relationship between EEG frequency characteristics and RT. Lansing, Schwartz, and Lindsley (1959) and Fedio, Mirsky, Smith, and Perry (1961) have all demonstrated that fast RT responses were accompanied by low voltage, fast EEG activity (alpha desynchronization), and slow RT responses were accompanied by slow EEG activity (alpha rhythms).

The work by Lansing et al. is representative and will be presented in detail. Visual RTs were measured under three conditions. Two conditions involved a foreperiod. That is, a warning stimulus (WS) was introduced at some time period prior to the reaction time stimulus (RTS). The third condition involved no warning stimuli. Short foreperiods (under 1000 msec.) resulting in the highest pe-centage of low voltage, fast EEG activity produced the fastest mean RTs (206 msec.), while extremely short foreperiods (under 250 msec.) resulted in a higher number of trials introduced prior to desynchronization and a mean RT of 280 msec. With no warning stimulus the mean RT was 280 msec. The savings in response speed were ascribed to the differential percentage of trials introduced during alpha desynchronization under the three conditions.

Further evidence in support of the relationship between brain wave period and RT was provided by Sruwillo (1961, 1968) who demonstrated statistically significant inter- and intra-individual correlations (r=0.72 and mean r=0.30) between auditory RTs and brain wave period. He developed the hypothesis that EEG cycle was the basic unit of time in terms of which events are programmed in the central nervous system.

Boddy (1971) reports in a review of research on the relationship between RT and EEG period that these relationships may not be as strong as indicated and might depend on the choice of sampling intervals utilized in previous investigations. He indicates that Lansing (1957) failed to find any intraindividual correlations, while Williams et al. (1962) only found such relationships in subjects who had undergone long sleep deprivation. Boddy reanalyzed much of the date reported on the relationship between RT and EEG period and suggests that the changes in RT may be due to phasic changes between alpha and theta frequency bands, rather than changes on the frequency continuum and may have produced the correlations noted. Morrell (1966) studied this hypothesis and found that EEG band (classified as alpha, mixed, or slow waves) predicted the RT of each trial. Boddy (1971) suggests that Morrell's findings indicate that RT can be better explained on the basis of level of activation rather than on the basis of an implicit timing mechanism.

Further discrepant information regarding the desynchronization response and RT was presented by Hermelin and Venables (1964) who were unable to find any relationship between alpha blocking and reaction time even under alerted conditions with warning stimuli. Thompson and Botwinick (1966) also failed to find any relationship between the alpha blocking response over a series of investigations utilizing differing foreperiod intervals.

In summary, some controversy exists regarding the relationship between EEG period and alpha blocking response and the reaction time measure. It appears that the best results have been obtained when phasic changes in EEG period have been utilized to predict RT (Morrell, 1966). None of the investigators mentioned, however, have undertaken to compare the EEG frequencies immediately prior to the WS to those immediately after the WS. These phasic changes in EEG activity may be much more important in determining the RT response. This postulation is also in line with the supposition that physiological activation or arousal is a multicomponent process with at least a tonic and a phasic component.

With regard to the possible hemispheric laterality of the phasic activation process as measured by the simple RT paradigm some evidence exists indicating that the nondominant right hemisphere processes RT stimuli more rapidly. Jeeves and Dixon (1970) presented suprathreshold light stimuli via a complex electrical system to the retinal fields projecting to the two cerebral hemispheres and found that the right hemisphere was consistently more rapid in responding than the left hemisphere. This finding was uniform across several different studies involving different stimulus parameters, different response procedures, and differing foreperiods. It also appeared that when single handed responding was utilized that the fastest responses were obtained when the RT stimulus was projected to the right hemisphere and the preferred right hand was utilized. It must be mentioned that these authors made no effort to manipulate the arousal of their subjects and it was the RT stimulus and not the warning stimulus that was projected to the hemispheres.

In summary, the activation process must be treated as a hypothetical construct which can only be truly defined operationally. That is, activation is defined in terms of the operations utilized to manipulate and measure it within specific experimental stiuations. It is also best explained as a multicomponent process expressed differently in the various physiological response systems and within the various behavioral paradigms utilized to manipulate it. Thus the difficulties in correlating the many measures of activation consistently can be explained by the differing components of activation assessed by the different methods and the differing sensitivities of the methods to the several aspects of the activation process.

The present investigation will utilize the simple RT paradigm in that it would seem to reflect the "readiness to respond" component of activation utilized by Duffy (1962) in her definition and discussion of activation and behavior. The EEG will also be utilized as a measure of physiological neural activation in that it has been long utilized as a measure (Lindsley, 1944) and it offers some promise in elucidating the laterality effects hypothesized in the statement of the research problem to follow.

CHAPTER III

STATEMENT OF THE PROBLEM

As has been indicated, the concept of activation in psychology has been complicated the the inherent difficulties of defining the construct in question, and the many basic psychological processes which have been attributed to activation. For the purposes of the present investigation the discussion of Duffy (1962) provides an adequate operational definition of activation in terms of readiness to respond. It is in terms of readiness to respond that the conceptions of Hernandez-Peon (1966) regarding directed attention and Heilman and Valenstein's (1972) conception of phasic activation defects in the unilateral neglect syndrome can be integrated into a common theoretical framework.

Fron Hernandez-Peon's viewpoint directed attention involved the inhibition of cortical centers not involved in the direct processing of significant environmental information and the activation of those centers directly involved in processing that information. Heilman and Valenstein (1972) have developed a model involving a cortical-RAS-cortical loop to account for this process and have amassed some data from both the physiological and behavioral realms in support of their model. They hypothesize that it is a disconnection in this loop that is responsible for the defects in orienting seen in patients with the unilateral neglect syndrome and, possibly, the additional defects attributed to these patients. These defects include emotional responsiveness (Gainotti, 1972), memory defects (Heilman, Watson, and Schulman, 1974), but most certainly defective orienting or phasic activation.

The seeming predominance of the unilateral neglect syndrome after lesions of the right cerebral hemisphere has led to the speculation that it is this hemisphere which is functionally predominant in the phasic activation response with the left hemisphere capable of some materaial specific activation, but certainly less than the seeming nonspecific activation processes of the right hemisphere.

The simple RT paradigm involving lateralized warning stimuli to activate the respective hemispheres would seem to provide a behavioral paradigm by which the possible laterality of this process might be studied. The electroencephalographic recording and frequency analysis over the two hemispheres might also provide evidence of the laterality of this process.

Thus the major hypotheses of the present investigation can be expressed as follows:

1. Lateralized warning stimuli will uniformly decrease RTs, but warning stimuli directed to the right cerebral hemisphere will have a more marked effect on RT responses performed with the preferred right hand than will warning stimuli directed to the language dominant left hemisphere.
2. Electroencephalographic frequencies will be modified over the left hemisphere to a greater extent by warning stimuli directed to the right hemisphere than will the frequencies of the right

hemisphere be altered by warning stimuli directed to the left hemisphere.

The changes predicted by hypothesis 1. are expected to be seen more directly with the preferred right hand in that the motor predominance of the left hemisphere might confound the RTs obtained with the left hand if the present hypothesis is correct. It is expected, however, that the main effect of the laterality of the warning stimulus will be of sufficient strength to support the hypothesis of right hemisphere dominance in the activation process despite the motor differences between the two hands.

CHAPTER IV

METHOD

Subjects

Twenty-four right-handed subjects (Ss), 12 male and 12 female, ages between 18 and 24 were obtained from an undergraduate psychology subject pool where participation in experiments fulfilled part of the requirements of their introductory course. All Ss met the following screening criteria: No use of the left hand for any skilled activity; no history of epileptic seizures, severe head injury, or prior EEG abnormality. Ss who appeared unusually fatigued at the start of an experimental session were rescheduled for another time. Ss who required eyeglasses were required to wear them for the duration of the experiment.

Apparatus

The stimulus display for the present experiment consisted of two lateralized warning lights (WS) which were red light emitting diodes, and a green light emitting diode as a reaction time light (RTS). These stimuli were emplaced in a matte black board with the WS placed six inches to the left and right of the centrally located RTS. A chin rest apparatus was positioned such that the Ss were 21 inches from the display and the stimuli were at eye level with the RTS centrally located. With this configuration the WS were 16 degrees of visual angle lateral to the RTS. All Ss reported the entire stimulus display to be easily detectable and far above threshold with the room lights dimmed.

Reaction times (RTs) were obtained via a centrally located microswitch which the Ss were instructed to release at the onset of the RTS. Reaction times were recorded utilizing a Southwest Technical Products timer accurate to one millisecond.

Electroencephalographic recording was accomplished via a Grass Model 7 research polygraph equipped with eight EEG amplifiers. Grass gold cup electrodes were placed at F3, F4, C3, C4, P3, P4, 01, and 02 according to the International 10-20 System. Bipolar recording was utilized with the montage F3-C3, C3-P3, P3-01, and F4-C4, C4-P4, P4-02. The time constants were set so that 1/2 the smplitude points were at 1 and 90 Hertz. A 60 Hertz notch filter was also utilized to eliminate any extraneous frequencies from the unshielded experimental room utilized.

The presentation of the stimuli and their timing were accomplished via "Digi-Bit" digital logics obtainable from BRS. LVE. Pulses from these logics were also utilized as event markers on the EEG.

All EEG channels and the digital logics were calibrated for equal output with a standard signal before and after each recording.

Procedure

While the EEG electrodes were being placed, Ss were presented with the stimulus display and the other equipment in the room and their permission was obtained to pursue the experiemtn. Each S then completed three practice trials, one each from the WS conditions.

A trial was initiated by a loud tone at which the Ss depressed the RT microswitch in preparation for the RTS. After delays of 12, 18, or 22 seconds the stimulus sequence was presented.

A stimulus sequence was composed of a left WS (LWS), no WS (-WS), and a right WS (RWS) followed by the RTS after either a 1 or 2 second foreperiod. A ten second delay followed each stimulus sequence before the tone signaling the next rrial. In the case of the -WS condition the foreperiod parameters were maintained despite the absence of the WS. Thus, all trials were of the same duration despite the WS condition. Ss were instructed to release the microswitch as soon as possible after the onset of the RTS. Ss were not given feedback, but were continuously informed that the quickest possible response was desired.

Occasionally an S would anticipate the RTS and release the microswitch at the onset of the WS. In this case, the trial was discarded and repeated again at the end of each block of trials.

At the tone the Ss were instructed to fixate on the central RTS as closely as possible without straining their eyes. Each S was observed to insure their cooperation and the EEG was monitored for eye movement artifacts. Any trial with direct observation of eye movement or EEG evidence of such eye movements was discarded and repeated at the end of the block of trials.

The three WS conditions, the three delay conditions, and the two foreperiod conditions were randomized into blocks of 18 trials. These blocks were randomized again into two separate sequences of five blocks of trials. The order of the presentation of these two sequences was varied from S to S such that one S would complete sequence one with his right hand and sequence two with his left hand, while the next S would receive the opposite order. This randomization procedure resulted in each S completing 180 trials, ninety with each hand.

Ss were allowed a five minute rest period at the end of each block of trials. The entire experimental procedure required approximately three hours for completion and was divided into two 1 1/2 hour sessions over the course of two days. Ss were always run at the same time of day from session to session and sessions were always scheduled during the afternoon to minimize any circadian influences on EEG or RT data.

EEG Data Reduction

The EEG data obtained in the present experiment was processed utilizing a Nicolet Med-80 data processing system equipped with an analog to digital converter and storage facilities for the large amount of data obtained. Prior to processing, each channel of EEG data was further filtered to eliminate all frequencies above 60 Hertz. The computer was programmed to utilize an event marker produced by the digital logics one second prior to the onset of the WS and then to digitize 2 seconds of EEG data. Thus the 1 second prior to the WS and the 1 second of EEG following the WS might be compared.

After ninety trials were collected in this manner, or the entire experimental session comprised of the trials given to one hand, the data were analyzed in terms of frequency content. This was accomplished by utilizing a Fourier transform procedure (Cooper, 1973) which transformed each second of EEG data into a power frequency spectra, a mathematical representation of the total neergy content at each frequency of interest. The power frequency spectra from each trial with the same WS condition (thirty trials) were added together and this total divided by thirty to obtain an average frequency spectra from each second of data in a WS condition. Change scores for each WS condition were computed by subtracting the power in each of the standard physiological bands (Delta, Theta, Alpha, Beta I, and Beta II) of the 1 second prior to the WS from the 1 second after the WS. This was accomplished for each EEG derivation and within each hand. Thus, for each subject, a matrix of change scores was obtained for each EEG derivation for each WS condition for each ninety trial session. These matrices of change scores were submitted to an analysis of variance for repeated measures with the within subject variables being EEG band, WS condition, EEG derivation, hemisphere, and hand. The between subject variable of sex was also examined.

The enormity of this data reduction procedure required that only twelve Ss be utilized for the EEG data analysis. These Ss were randomly selected from the twenty-four original Ss without knowledge of their RT results.

Reaction Time Data Reduction

The RTs from each session were analyzed in terms of mean RT in milliseconds within each WS x foreperiod condition. The delay interval was not of concern in that it was utilized only to break up any expectancy effect that the Ss might build up over the lengthy sessions were each trial of the same duration. The foreperiod, however, had been found to influence the effect of the WS on RT (Lansing, Schwartz, and Lindsley, 1959). Thus, the fifteen trials within each WS x foreperiod condition from each session were averaged to obtain the mean scores for further analysis.

Within each subject the mean score for each WS x foreperiod condition was subtracted from the analogous -WS x foreperiod condition resulting in difference scores for each WS x foreperiod condition within each hand. The resulting matrix of scores was subjected to an analysis of variance for repeated measures with the within subject variables being WS, foreperiod, and hand; and the between subject variable of sex of the S. All twenty-four replicates were utilized for the RT analysis.

CHAPTER V

RESULTS

The results of the present experiment will be presented in two sections. The first section will concern itself with the RT decrease resulting from the warning stimuli when compared to an RT obtained without warning stimuli, but with the same time parameters. The second section will present the EEG frequency changes obtained from both cerebral hemispheres as a result of the warning stimuli.

Reaction Time Results

RTs obtained after a warning stimulus were uniformly over 100 milliseconds faster than those obtained without a warning stimulus, but under the same time parameters. The overall mean scores obtained from the three WS conditions (collapsing across sex, hand and foreperiod) are presented in Table I.

TABLE I

Mean Reaction Times (Milliseconds)
Within Warning Stimulus Conditions

	Left Warning	No Warning	Right Warning
$\overline{M}$	247.96 msec.	359.23 msec.	253.18 msec.
S.D.	39.05 msec.	52.10 msec.	41.49 msec.

As can be seen, the RTs resulting from a warning stimuli are all over 100 milliseconds faster than those obtained without any warning. It should also be noted, however, that the RTs obtained without a warning are much more variable. It was this differing variability and the inherent skewness of RT distributions that prompted the use of difference scores outlined in the previous section. That is, mean difference scores were utilized in a mixed-models analysis of variance. Within each 90 trials the Ss completed with each hand the fifteen RTs representing a warning stimulus by foreperiod cell were averaged and subtracted from the mean RT calculated for the no warning stimulus cell with the same time parameters. This procedure resulted in a mean difference in RT for each condition which was more normally distributed and fulfilled the assumptions of the analysis of variance statistical technique.

The results of the analysis of variance are presented in Table II. As can be seen, the main effect of warning stimulus is highly significant and approaches the .01 level of confidence. Also significant are the interaction between warning stimulus, foreperiod, and hand used. The interaction between foreperiod and hand used is also significant.

The main effect of sex of the S was not found to be significant, but the interaction between WS, hand used, and sex falls only slightly short of the .05 criterion.

The mean differences in RT produced by the WS are as follows. The LWS produced a mean decrease of 111.27 msec., while the RWS produced a decrease of 106.05 msec. The significance of the main effect of WS was achieved by the greater decrease due to the LWS across

TABLE II

Summary of Analysis of Variance
Mixed Models Analysis with Repeated Measures on Three Factors

Source	SS	df	Ms	F	p
Warning Stimulus	1305.91	1	1305.91	7.12	0.014*
Foreperiod	5.05	1	5.05	0.00	0.946
Warning Stimulus x Foreperiod	200.74	1	200.74	1.03	0.321
Hand Used	1657.20	1	1657.20	0.76	0.392
Warning Stimulus x Hand Used	641.65	1	641.65	3.29	0.083
Foreperiod x Hand Used	3939.17	1	3939.17	5.20	0.033*
Warning Stimulus x Foreperiod x Hand Used	398.12	1	398.12	4.74	0.041*
(Between Subjects Factor)					
Sex	4200.70	1	4200.70	0.54	0.469
Warning Stimulus x Sex	307.53	1	307.53	1.68	0.209
Foreperiod x Sex	1431.92	1	1431.92	1.35	0.258
Warning Stim. x Foreperiod x Sex	25.47	1	25.47	0.13	0.721
Hand x Sex	1276.21	1	1276.21	0.59	0.451
Warning Stim. x Hand x Sex	791.41	1	791.41	4.06	0.056
Foreperiod x Hand x Sex	49.97	1	49.97	0.07	0.800
Warning Stim. x Foreperiod x Hand x Sex	263.96	1	263.96	3.14	0.090

*p .05

TABLE II

Continued

Source	SS	df	Ms	F	p
Error Between Subject Groups	170203.92	22	7736.54		
Error (Warning Stimulus)	4035.99	22	183.45		
Error (Foreperiod)	23312.35	22	1059.65		
Error (Warning Stim. x Foreperiod)	4278.65	22	194.48		
Error (Hand)	47775.33	22	2171.61		
Error (Warning Stim. x Hand)	4289.66	22	194.98		
Error (Foreperiod x Hand)	16657.55	22	757.16		
Error (Warning Stim. x Foreperiod x Hand)	1848.99	22	84.05		
TOTAL	288897.45	191			

TABLE III

Mean RT Differences Due to Warning Stimuli*

FOREPERIOD		LEFT WARNING		RIGHT WARNING
		RIGHT HAND TRIALS		
1 Second	M	-117.314 msec.	M	-103.517 msec.
	SD.	32.941 msec.	SD.	40.330 msec.
2 Second	M	-103.005 msec.	M	-99.058 msec.
	SD.	40.762 msec.	SD.	40.380 msec.
		LEFT HAND TRIALS		
1 Second	M	-107.594 msec.	M	-106.870 msec.
	SD.	36.767 msec.	SD.	39.346 msec.
2 Second	M	-117.164 msec.	M	-114.769 msec.
	SD.	36.855 msec.	SD.	37.893 msec.

N = 24

*Each Mean Value is the Result of Averaging 15 Trials Within Each Warning Stimulus by Foreperiod Cell and Subtracting that Mean from the Mean Obtained from the Appropriate No Warning Cell.

TABLE IV

Newman-Keuls Post-Hoc Comparisons of Mean+ Differences in RT Due to Warning Stimuli

(Mean Differences)

ORDERED MEANS	2	3	4	5	6	7	8
1. -99.058 msec. (RWS, 2 sec., RH)	3.947	4.559	7.812*	8.536**	15.711**	18.106**	18.256**
2. -103.005 msec. (LWS, 1 sec., RH)	-	.512	3.865	4.589	11.764**	14.159**	14.309**
3. -103.517 msec. (RWS, 1 sec., RH)		-	3.353	4.077	11.252**	13.647**	13.759**
4. -106.870 msec. (RWS, 1 sec., LH)			-	.724	7.899*	10.294**	10.444**
5. -107.594 msec. (LWS, 1 sec., LH)				-	7.175*	9.570**	9.720**
6. -114.769 msec. (RWS, 2 sec., LH)					-	2.395	2.545
7. -117.164 msec. (LWS, 2 sec., LH)						-	.150
8. -117.314 msec (LWS, 1 sec., RH)							-

+Winer (1967)

*= p .05

**= p .01

TABLE V

Mean Decreases in Reaction Time Due to Foreperiod*
Between a Warning and Reaction Stimulus
Without Regard to Lateralization
of the Warning

FOREPERIOD	RIGHT HAND		LEFT HAND	
1 Second	$\overline{M}$.	-110.415 msec.	$\overline{M}$.	-107.032 msec.
	SD.	37.462 msec.	SD.	38.080 msec.
2 Second	$\overline{M}$.	-101.032 msec.	$\overline{M}$.	-115.967 msec.
	SD.	40.620 msec.	SD.	37.397 msec.

N = 24

*Each Mean Value Represents the Average of the Foreperiod by Hand-used Cell Means Across all 24 Ss.

TABLE VI

Newman-Keuls Post-Hoc Comparisons of Mean#
Differences in Reaction Time Due to
the Foreperiod Between the Warning
and Reaction Time Stimulus

DIFFERENCES BETWEEN MEANS

ORDERED MEANS		2	3	4
1. -101.032 msec (2 sec., Right H.)	-	6.200*	9.383**	14.935**
2. -107.032 msec. (1 sec., Left H.)		-	3.183	8.735*
3. -110.415 msec. (1 sec., Right H.)			-	5.522
4. -115.415 msec. (2 sec., Left H.)				-

#Winer (1967)

*= p .05

**= p .01

all foreperiod, hand, and subject replications. The strength of this relationship is indicated in the graphic presentation of the significant interactions involving the WS factor. These interactions are presented in Figures I and II. The interaction involving the sex of the S is also presented as Figure III despite its falling short of the criterion for significance.

Tables III and IV present the mean decreases in RT due to the various WS and foreperiod combinations within each hand, and the Newman-Keuls (Winer, 1967) post-hoc pairwise comparisons of these mean decreases. As can be seen the LWS almost uniformly provides faster RTs than does the RWS, but this is significant only with the right hand at the one second foreperiod. The left hand was faster with the LWS, but not significantly so. Interestingly, however, the left hand was faster under both WS conditions only under the longer 2 second foreperiod.

This relationship is also presented in the graphic presentation of the foreperiod x hand interaction in Figure II. The mean RTs and post-hoc tests of significance of this interaction effect are presented in Tables V and VI.

Post-hoc comparisons were not attempted among the mean decreases in RT within the sex interaction in that this interaction did not achieve the .05 level of confidence.

Electroencephalographic Results

The changes in EEG band power within the three WS conditions are presented graphically in Figure IV and in tabular form in Table VII. As can be seen from Figure IV the band which most differentiates among the

FIG. I DECREASE IN REACTION TIME RESULTING FROM WARNING STIMULUS PRESENTATION: FOREPERIOD X HAND INTERACTION

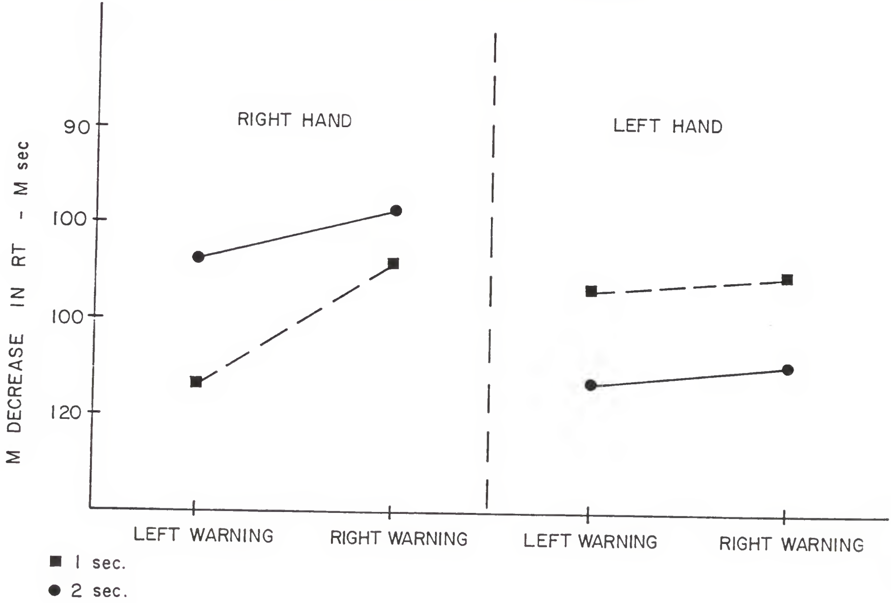

FIG. II DECREASE IN REACTION TIME RESULTING FROM FOREPERIOD INDEPENDENT OF WARNING STIMULUS CONDITION

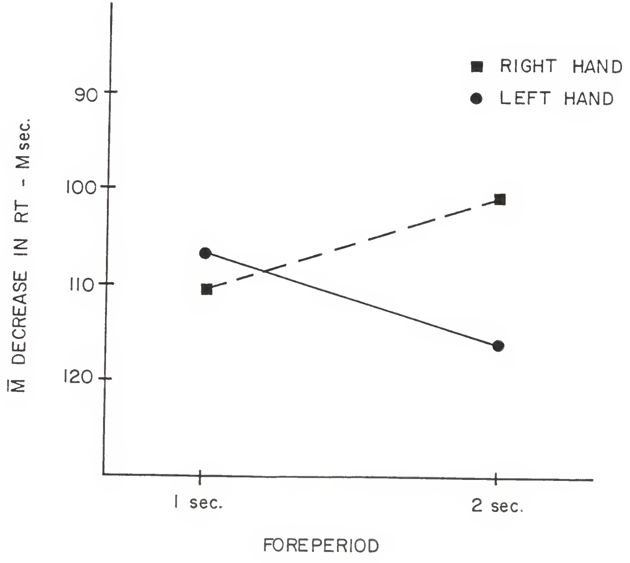

FIG. III MEAN DECREASE IN REACTION TIME RESULTING FROM A LATERALIZED WARNING STIMULUS-SEX INTERACTION.

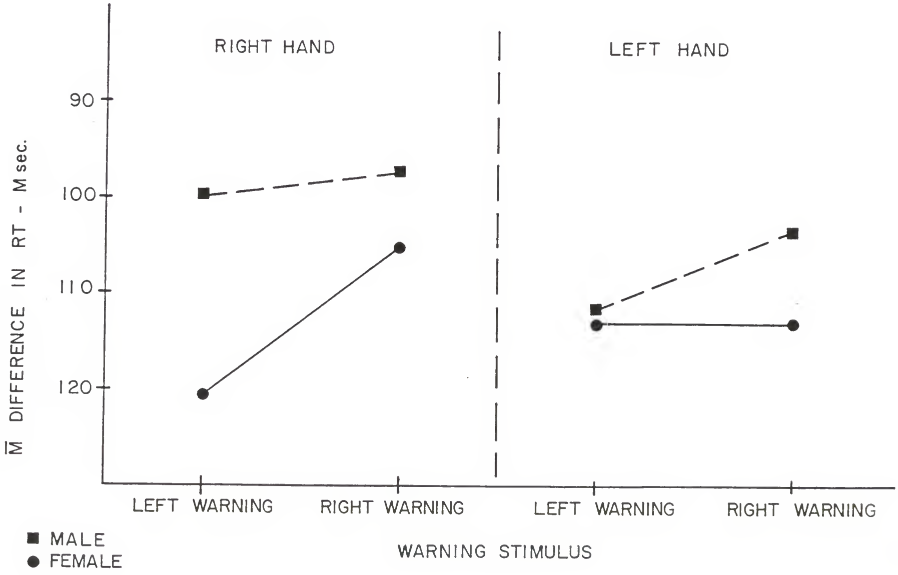

FIGURE IV CHANGE IN EEG BAND POWER WITHIN WARNING STIMULUS CONDITIONS.

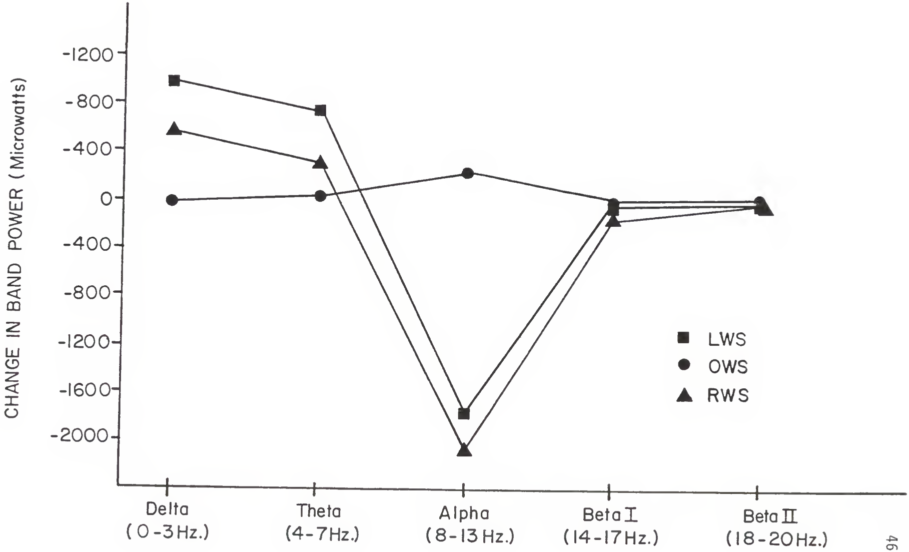

TABLE VII

Change in EEG Band Power Due to* Warning Stimulus Condition

EEG BAND

WARNING CONDITION		Delta (0-3 Hertz)	Theta (4-7 Hertz)	Alpha (8-13 Hertz)	Beta I (14-17 Hertz)	Beta II (18-20 Hertz)
No Warning Stimulus	M.	-16.104 mw.#	19.312 mw.	226.594 mw.	-42.490 mw.	-0.906 mw.
	SD.	738.914 mw.	628.657 mw.	1451.183 mw.	190.570 mw.	188.576 mw.
L. Warning Stimulus	M.	982.406 mw.	738.698 mw.	-1764.667 mw.	-83.958 mw.	-53.896 mw.
	SD.	1776.404 mw.	1345.409 mw.	2593.558 mw.	264.092 mw.	206.052 mw.
R. Warning Stimulus	M.	581.021 mw.	289.562 mw.	-2186.594 mw.	-131.750 mw.	-38.073 mw.
	SD.	1076.294 mw.	1199.075 mw.	3058.632 mw.	327.149 mw.	150.837.mw.

*Each Mean Value Represents the Mean of 96 Replicates (2 leads x 2 hemispheres x 2 hands used x 6 Ss x 2 Sexes = 96)

#All Values are Expressed in Microwatts or 10^{-6} Watts.

WS conditions is the Alpha band. It was decided to pursue the WS changes within this band and not the Delta and Theta bands in that the changes in these bands were felt to be largely due to the visual evoked response (VER) to the WS and not a change in inherent frequencies.

In order to maximize the homogeneity of variance within the analysis of variance it was decided to compute a separate analysis within each lead. That is, a separate analysis of variance was accomplished within the parietal and occipital leads. The results of these analyses are presented in Tables VIII and IX.

Within the parietal analysis it can be noted that the main significant factors are the WS condition ($F_{2,20} = 11.85$), and the interaction between WS and cerebral hemisphere ($F_{2,20} = 4.20$). The mean differences in Alpha power between the WS conditions and the Newman-Keuls post-hoc comparisons of these mean differences are presented in Tables X and XI. Both of the LWS and RWS resulted in marked decreases in Alpha power which were highly significant when compared to the OWS mean difference; but these changes were not significantly different from each other.

The interaction between WS condition and hemisphere is presented in Figure V and the mean differences in Alpha power and post-hoc comparisons of the mean differences are presented in Tables XII and XIII.

As can be appreciated from Figure V and the tables involving the hemisphere by WS interaction, all of the values involving a WS are significantly different from those obtained without warning. The uniformity of the OWS values and their approximation of no chante in Alpha power would seem to suggest that the changes seen with the WS are not due to any baseline shift, but to the WS themselves.

TABLE VIII

Summary of Analysis of Variance (Repeated Measures on 4 Factors)
of Mean Changes in Alpha Power--Parietal Leads--

SOURCE OF VARIATION	SUMS OF SQ.	df	MEAN SQ.	F	SIG.
Hemisphere	12693781.36	1	12693781.36	3.25	NS
Warning Stimulus	314774232.87	2	157387116.43	11.85	.001
Hand Used	48914.69	1	48914.69	0.01	NS
Hemisphere x Warning St.	23238366.68	2	11619183.34	4.20	= .030
Hemisphere x Hand Used	3742935.11	1	3742935.11	1.19	NS
Warning St. x Hand Used	4084479.76	2	2042239.88	0.38	NS
Hemisphere x Warning St. x Hand Used	2069812.51	2	1034906.25	0.57	NS
(Between Subjects Factors)					
Sex	80422034.69	1	80422034.69	1.82	NS
Hemisphere x Sex	14162677.77	1	14162677.77	3.62	NS
Warning Stimulus x Sex	59381473.18	2	29690736.59	2.24	NS
Hand Used x Sex	1494098.77	1	1494098.77	0.29	NS
Hemisphere x Warning St. x Sex	3308171.76	2	1654085.88	0.60	NS
Hemisphere X Hand Used x Sex	2815124.69	1	2815124.69	0.89	NS
Warning St. x Hand Used x Sex	10693772.34	2	5346886.17	0.98	NS
Hemisphere x Warning St. x Hand Used x Sex	113312.09	2	56656.04	0.03	NS
(Error Terms)					
Error Between Subject Groups	441481252.47	10	44148125.24		
Error (Hemisphere)	39109095.02	10	3910909.50		
Error (Warning Stimulus)	265683258.27	20	13284162.91		

TABLE VIII

Continued

SOURCE OF VARIATION	SUMS OF SQ.	df	MEAN SQ.	F	SIG.
Error (Hemisphere x Warning St.)	55296564.88	20	2764828.24		
Error (Hand Used)	52148725.36	10	5214872.53		
Error (Hemisphere x Hand Used)	31465660.36	10	3146566.03		
Error (Warning St. x Hand Used)	108807981.55	20	5440399.07		
Error (Hemisphere x Warning St. x Hand Used)	36138932.72	20	1806946.63		
TOTAL	1563174659.00	143			

FIGURE V CHANGE IN ALPHA POWER DUE TO A LATERALIZED WARNING STIMULUS PARIETAL LEADS

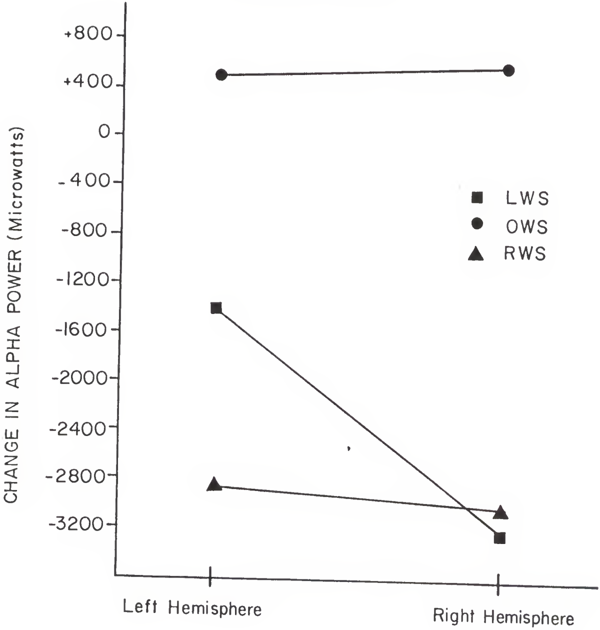

TABLE IX

Summary of Analysis of Variance (Repeated Measures on 4 Factors)
of Mean Changes in Alpha Power--Occipital Leads--

SOURCE OF VARIATION	SUMS OF SQ.	df	MEAN SQ.	F	SIG.
Hemisphere	19019774.69	1	19019774.69	6.63	0.028
Warning Stimulus	56646463.38	2	28323231.69	4.99	0.018
Hand Used	754871.36	1	754871.36	0.46	NS
Hemisphere x Warning St.	10544321.72	2	5272160.86	2.88	NS
Hemisphere x Hand Used	358801.00	1	358801.00	0.19	NS
Warning Stimulus x Hand Used	5458288.38	2	2729144.19	1.33	NS
Hemisphere x Warning St. x Hand Used	886747.16	2	443373.58	0.48	NS
(Between Subjects Factors)					
Sex	9972964.00	1	9972964.00	1.48	NS
Hemisphere x Sex	72092.25	1	72092.00	0.03	NS
Warning Stimulus x Sex	8759710.50	2	4379855.25	0.77	NS
Hand Used x Sex	1216241.36	1	1216241.36	0.74	NS
Hemisphere x Warning Stimulus x Sex	6863664.50	2	3431832.25	1.88	NS
Hemisphere x Hand Used x sex	77841.00	1	77841.00	0.04	NS
Warning Stimulus x Hand Used x Sex	171442.05	2	85721.02	0.04	NS
Hemisphere x Hand Used x Warning St. x Sex	3617030.16	2	1808515.08	1.96	NS
(Error Terms)					
Error Between Subject Groups	67590882.05	10	6759088.20		
Error (Hemisphere)	28678427.22	10	2867842.72		
Error (Warning Stimulus)	113627330.61	20	5681366.53		

TABLE IX

Continued

SOURCE OF VARIATION	SUMS OF SQ.	df	MEAN SQ.	F	SIG.
Error (Hand Used)	16535264.44	10	1653526.44		
Error (Hemisphere x Warning St.)	36554121.61	20	1827706.08		
Error (Hemisphere x Hand Used)	18709576.50	10	1870957.65		
Error (Warning St. x Hand Used)	41155195.38	20	2057759.76		
Error (Hemisphere x Warning St. x Hand Used)	18442959.16	20	922147.95		
TOTAL	465714010.55	143			

TABLE X

Mean Changes in Alpha Power Within Warning Stimulus Conditions (Parietal Leads)*

	LEFT WARNING	NO WARNING	RIGHT WARNING
$\overline{M}$.	-2370.000 mw.#	473.812 mw.	-2890.062 mw.
S.D.	3296.751 mw.	1647.574 mw.	3524.950 mw.

*Each Value Represents the Mean of 48 Comparisons
(2 Hemispheres x 2 Hands Used x 2 Sex x 6 Replicates = N = 48)

#All Values are Expressed in Microwatts or 10^{-6} Watts.

TABLE XI

Newman-Keuls Post-Hoc Comparisons of Mean+ Changes in Alpha Power Within Warning Stimulus Conditions (Parietal Leads)

	MEAN DIFFERENCES		
ORDERED MEANS	1	2	3
473.812 mw. (No WS)	-	2843.812**	3363.874**
-2370.000 mw. (Left WS)		-	520.062
-2890.062 mw. (Right WS)			-

+Winer (1967)

** = p .01

TABLE XII

Mean Changes in Alpha Power Within Hemisphere and Warning Stimulus Conditions (Parietal Leads)*

LEFT WARNING	NO WARNING	RIGHT WARNING
	Left Hemisphere	
M. -1506.333 mw.#	M. 453.417 mw.	M. -2842.625 mw.
SD. 2892.158 mw.	SD. 1136.070 mw.	SD. 3520.933 mw.
	Right Hemisphere	
M. -3233.667 mw.	M. 494.208 mw.	M. -2937.500 mw.
SD. 3446.842 mw.	SD. 2034.088 mw.	SD. 3528.324 mw.

*Each Value Represents the Mean of 24 Comparisons (2 Hands Used x 2 Sex x 6 Replicates = N = 24)

#Each Value is Expressed in Microwatts or 10^{-6} Watts

TABLE XIII

Newman-Keuls Post-Hoc Comparisons of Mean Changes# in Alpha Power
Within Hemisphere and Warning Stimulus Conditions
(Parietal Leads)

Mean Differences

ORDERED MEANS	1	2	3	4	5	6
1. 494.208 mw. (No WS, R Hem.)	-	41.208	2000.541**	3336.833**	3431.708**	3727.875**
2. 453.417 mw. (No WS, L Hem.)		-	1959.750**	3296.042**	3390.917**	3687.084**
3. -1506.333 mw. (Left WS, L Hem.)			-	1336.292*	1431.167*	1727.334**
4. -2842.625 mw. (Right WS, L Hem.)				-	94.875	391.042
5. -2937.500 mw. (Right WS, R Hem.)					-	392.167
6. -3233.667 mw. (Left WS, R Hem.)						-

#Winer (1967)

* = p .05

** = p .01

It is also noteworthy that within the left hemisphere the RWS produced the greatest decrease in Alpha power which was significantly greater than that produced by the LWS. Within the right hemisphere, however, both WS produced an equal decrease in Alpha power. This pattern of change is, in fact completely opposite from what was expressed in the initial hypotheses regarding electroencephalographic variables.

This pattern of results is not duplicated within the occipital leads as is indicated in Table IX. Within this lead placement the only significant effects are the main effects of hemisphere and WS. The main effect of hemisphere, in this case, is largely due to a decrease in the Alpha suppression effect over the right occipital lead where the overall change due to both WS was only -524.254 mw., as compared to a change of -1892.319 mw. found over the right parietal lead. A change of -1251.125 mw. was noted over the left occipital lead which is comparable to the change noted over the homologous parietal lead. It is noteworthy, however, that the relative relationship of the three WS conditions without regard to hemisphere is unchanged when compared to the parietal values. These mean changes in Alpha power within the occipital leads are presented in Tables XIV and XV. The hemisphere by WS interaction does not achieve a level of significance sufficient for pursuit of post-hoc analyses as was accomplished within the parietal leads.

As can be seen in the case of the occipital leads both changes in Alpha power are significantly different from the near zero change associated with the -WS condition.

TABLE XIV

Mean Changes in Alpha Power Within Warning Stimulus Conditions (Occipital Leads)*

	LEFT WARNING	NO WARNING	RIGHT WARNING
$\overline{M}$.	-1159.333 mw.#	-20.625 mw.	-1483.125 mw.
S.D.	1360.757 mw.	1172.659 mw.	2301.185 mw.

*Each Value Represents the Mean of 48 Comparisons
(2 Hemispheres x 2 Hands Used x 2 Sex x 6 Replicates = N - 48)

#All Values are Expressed in Microwatts or 10^{-6} Watts

TABLE XV

Newman-Keuls Post-Hoc Comparisons of Mean+ Changes in Alpha Power Within Warning Stimulus Conditions (Occipital Leads)

MEAN DIFFERENCES

ORDERED MEANS	1	2	3
-20.625 mw. (No WS)	-	1138.708**	1462.500**
-1159.333 mw. (Left WS)		-	323.792
-1483.125 mw. (Right WS)			-

+Winer (1967)

** = p .05

CHAPTER VI

DISCUSSION

The measurement of RT as a dependent variable in experiments in both cognitive and physiological psychology probably predates the existence of both disciplines as formal areas of investigation. As such it is bound up with preconceptions and assumptions that are often not questioned or considered in its selection as a measure. The resurgence of the RT measure in cognitive psychology is not hard to understand, however, when it is considered that the events of interest in this area most often take place without overt activity. Thus, by default, it is often necessary to assume that the RT response can give an avenue of approach to the timing and, more remotely, the composition of otherwise unobservable mental events.

In the case of the present investigation, the RT measure can be considered as both the vehicle through which an otherwise unobservable process can be measured, but also a component of that process. This is to say, that in its operational definition as readiness to respond, the activation process is defined by the response speed of the organism; and, in the present experimental paradigm, the activation process is measured via the actual RT to a stimulus display.

While the relationship between RT and arousal has not always been clear at least some direct evidence supports the contention that arousal, in its phasic stimulus-related construction, can be measured by the duration of a stimulus-response event. In the present case, it is immediately apparent that the RTs obtained from the warned conditions far surpassed those from the unwarned condition in terms of speed.

In the light of this discussion the data from the present investigation are interpreted as supporting the hypothesis that the right cerebral hemisphere is functionally predominant in the mediation of the phasic arousal response. The strength of the F test (7.12; 1, 22 df; p = .014) suggests that the superiority of the LWS in prodicing faster reaction times extended over all of the replicates and over the foreperiod and hand used factors as well. It was only within the right hand and at the shorter one second foreperiod that the superiority of the LWS achieved significance, but in terms of the present hypothesis, this is an even more critical observation. That is, the LWS was able to decrease the RT obtained from the contralateral right hand more than the ipsilateral RWS.

The RT data obtained from trials completed with the nonpreferred left hand are more difficult to interpret. When the lateralization of the WS was not considered it was noted that the RTs were reduced to a greater extent when the foreperiod was the lengthier two second time parameter. Intuitively it would be expected that the left hand would be slower in responding due to the differing manual dominance between the hands, but the greater reduction in warned RTs over a lengthier foreperiod is difficult to explain. It certainly cannot be completely explained on the basis of differing manual dominance between the hands.

Several explanations can be entertained on a speculative basis. The first would require that the activation produced by a WS is accomplished over a slower period of time when the response motor output is also controlled within the right hemisphere. Thus it could by hypothesized that activation within the right hemisphere spreads anatomically more slowly and is maintained longer than the analogous processes within the left cerebral hemisphere.

Data reported by Dimond and Beaumont (1972) in a study of the interhemispheric effects of fatigue have some bearing on this discussion. These authors report that there is a marked asymmetry between the cerebral hemispheres in terms of the RT response to digits presented in the two visual half fields. The right hemisphere, they indicate, fatigues in a different manner than the left. Their data would indicate that the right hemisphere fatigues less rapidly than the left hemisphere which is in agreement with the data reported for the present experiment.

Heilman, Schwartz, and Watson (1978), utilizing the GSR, report data suggesting a complex interaction between the cerebral hemispheres when activation processes are concerned. GSR responses recorded from the uninvolved ipsilateral limb of patients with vascular lesions demonstrated marked attenuation following lesions of the right hemisphere. Lesions of the left hemisphere, however, produced marked GSR responses to stimulation when compared to normal control subjects. These data suggest that the interhemispheric dynamics of the activation process are complex and require further elucidation.

To return to the present results, it would seem that the optimum foreperiod for demonstrating the LWS superiority in reducing RTs obtained from the right hand would be somewhat shorter than the lower limit of one second employed. This lower limit was required by the electroencephalographic data collection in that a shorter epic would have introduced a statistical artifact analysis involving physiological frequencies. Lansing, Schwartz, and Lindsley (1959), however, found that a 500 millisecond foreperiod was optimal in producing faster RTs and it could be reasoned that such a foreperiod would have demonstrated an even greater LWS superiority.

The electroencephalographic data reported in the present investigation did not support the original hypothesis that the frequencies observed over the left hemisphere would be more influenced by the LWS than the RWS. In fact the data are the obverse. It would appear that the right parietal area undergoes alpha suppression to both WS, while the left parietal leads are more influenced by the RWS than the LWS. The occipital leads did not provide any specific data regarding the relationship between WS and differential alpha suppression over the Two hemispheres.

Probably the most reasonable interpretation of these data is that the decrease in alpha power observed in the present experiment is not so much an indication of increased arousal, as was indicated by Lansing, Schwartz, and Lindsley (1959), but an indication of the involvement of the hemisphere in the processing of the warning stimulus information. This interpretation is amply supported by the long series of investigations reported by Galin and his colleagues (Galin and Ornstein, 1972; Doyle, Galin, and Ornstein, 1974; Ornstein and Galin, 1976). These writers contend tha local variation in alpha power reflects greater or lesser involvement in information processing and that it is the bilateral changes in alpha power that may be indicative of brainstem activity.

Taken in this context the present data are supportive of Bowers and Heilman's (1976) contention, based on their material specific warning stimulus paradigm, that the right hemisphere responds to all warning stimuli while the left hemisphere is most effected by verbal or right visual field stimuli. The present data indicate that the right parietal lobe is involved in processing all warning stimuli while the left parietal lobe responds significantly more to the RWS. It is also interesting to note that it is the right parietal lobe which has been most implicated in the unilateral neglect syndrome and one of the areas which produces the greatest RAS changes when stimulated (French, Hernandez-Peon, and Livingston, 1955).

The question may be asked then as to what is the electroencephalographic variable that best represents changes in activation and, thus, might have demonstrated the hemispheric specialization hypothesized. Several alternatives are suggested by the psychophysiological literature. Callaway and Yeager (1960) have demonstrated that the phase of the EEG cycle immediately prior to desynchronization was correlated with the RT response. Nishisato (1966) has suggested that it is the latency of the physiological response to the stimulus that is a more direct indication of arousal level. The amplitude of the averaged VER has been implicated by Haider, Spong, and Lindsley (1964) who found that RTs were shorter with higher amplitude VERs. Their correlations were as high as -.70 and their data is highly suggestive that attentional-arousal variables are directly involved in the shape of the VER.

Equally intriguing is the work of Loveless and Sanford (1974, 1975) who demonstrated that the contingent negative variation (CNV), a slow DC change in the EEG signal, had definite relationships with the RT response. This is particularly significant in that the paradigm in which the CNV is recorded is the simple warned RT paradigm utilized in the present invesitgation and would lend itself to a similar analysis.

In summary then, if interpreted as an indication of the information processing involvement of the hemispheres, the alpha suppression noted in the present experiment would indicate that the right parietal lobe responds and processes all WS no matter their lateralization. In terms of the phasic activation response, the EEG data are not supportive of the original hypothesis stating the functional predominance of the right cerebral hemisphere in producing EEG evidence of alerting of the left hemisphere to a greater extent than it would alert itself.

It would seem most appropriate at this point to state some predictions regarding the behavior of brain lesioned patients in the present experimental paradigm given homologous unilateral lesions. In the case of lesions of the right hemisphere the present data would suggest that reaction times obtained from patients would be bilaterally slow. Even with the ipsilateral uninvolved limb RTs would be slowed. Most important, however, would be the expectation that warning stimuli in either visual half field would have no effect on RT.

Given left hemispheric lesions the present data would suggest that certainly the RTs obtained from the involved right hand would be slowed, but given RTs from the uninvolved left hand, it would be expected that WS presented to the left visual half field would reduce RTs particularly if the foreperiod time parameter was slower.

Some preliminary data gathered by Heilman (Personal Communication) would support the latter prediction. Specifically, patients with right hemisphere lesions show markedly slowed RTs and their RTs are not reduced by any WS no matter its laterality of presentation. RTs from left hemisphere lesioned subjects and controls are not yet sufficient for comparison.

Needless to say, the present data must be treated conservatively until further replication and convergent manipulations of the relevant variables provide additional support for the present hypotheses and the cortical-RAS-cortical model of phasic activation on which they are based. It would seem, though, that the area of phasic activation with all of its difficulties provides another conceptual and operational paradigm with which to study the higher brain function and its hemispheric specialization. Indeed, Kinsbourne (1978) has stated that it is within the study of the differential effects of various manipulations on the activation of behaviors that a true topological understanding of the localization of higher cortical functions can be attained.

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BIOGRAPHICAL SKETCH

Thomas R. Van Den Abell was born on 7 September 1946 to Mary L. and Dominick A. Van Den Abell in Chicago, Illinois. He completed his primary education in the Roman Catholic school system and entered the seminary of the Archdiocese of Chicago where he completed his high school and junior college education in classical languages, theology, and philosophy. He received the degree of Bachelor of Science from Loyola University of Chicago in January of 1969. He entered the U.S. Army in June of 1969 and served as an instructor of field artillery cannon gunnery at Fort Sill, Oklahoma, and as a field artillery ballistic computer in the Republic of Viet Nam. He was awarded the Army Commendation medal and was recommended for the Bronze Star Medal at the time of his discharge from military service in 1971. Since that time he has been attending the University of Florida where he received his Master of Arts degree in 1974. He has since completed his internship in Clinical Psychology at the Boston Veterans Administration hospital where he specialized in Clinical Neuropsychology. He is presently married to the former Alexis Ann Diachenko.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Paul Satz

Paul Satz, Chairman
Professor of Clinical Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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